2019

A user-centered engineering approach to storage and access in high priority scenarios

Varun Anathasivan Srikrishnan
Iowa State University

A user-centered engineering approach to storage and access in high priority scenarios

by

Varun Ananthasivan Srikrishnan

A thesis submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Industrial Engineering

Program of Study Committee:
Richard Stone, Major Professor
Leifur Leifsson
Gary Mirka

The student author, whose presentation of the scholarship herein was approved by the program of study committee, is solely responsible for the content of this thesis. The Graduate College will ensure this thesis is globally accessible and will not permit alterations after a degree is conferred.

Iowa State University

Ames, Iowa

2019

TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

ACKNOWLEDGMENTS

I would like to thank the Director of Graduate Education, IMSE department, Dr Gary Mirka, and my major professor Dr Richard Stone, and my committee member Dr Leifur Leifsson, for their guidance and support throughout the course of this research. Additionally, I would like to thank the midwestern law enforcement agency for accommodating the experiments conducted and arranging for sworn officers to participate in the study.

I would also like to thank my friends, colleagues, the department faculty and staff for making my time at Iowa State University a wonderful experience. I want to also offer my appreciation to those who were willing to participate in my surveys and observations, without whom, this thesis would not have been possible.

ABSTRACT

This thesis aims at introducing the importance of the application of user-centered ideologies to the redesign and organization of storage spaces in high priority/time-critical industries such as law enforcement and introducing a new area of study that we call “organizational engineering”.

Throughout the thesis, the need for this new user-centered area of study was evaluated by carrying out experiments on six sworn officers in the miscellaneous equipment storage rooms at a midwestern law enforcement agency. This involved running the officers through a familiar scenario on the existing system design, redesigning and reorganizing the existing system using a combination of human-centered heuristics and quantitative data collected to develop an optimal design using a simulation software; Simio, running the officers on the new system and comparing the data obtained in both cases.

The analysis of both quantitative and qualitative data revealed that the new system was more intuitive to use and navigate through, easier to learn for new officers and enhanced greater visibility of the equipment in the room. The data also showed that the newly designed room was consistent with the design of the previous room and reduced the amount of wasted time by 48% and the associated cost by 49%. An ANOVA performed on the amount of wasted indicated a p-value of 0.008 and a paired t-test of the indicated a one-tailed p-value of 0.00033 suggesting the high possibility of a statistically significant difference between the two times. The data thus indicated that such user-centered redesigns could greatly reduce the amount of time devoted towards small duties that could greatly hinder the performance of more important tasks. The results obtained from this study indicate a potential to use this approach to storage systems in other high-priority/time-critical industries.

CHAPTER 1. GENERAL INTRODUCTION

User-centered design is an area that has sparked the interest of researchers and companies alike. The idea of developing machines for use my humans goes back as far as the early 1940's (Yerkes, Robert. M, 1941). The late 1940's and early 1950's saw applications of human engineering to the design of human-operated systems (Chapanis et al., 1949; Birmingham et al., 1954). Further, the aviation sector adopted the human engineering approach in the development of air-navigation and air-traffic control systems to improve human performance in these scenarios (Fitts, Paul M. et al., 1951) By the year 1957, about 45 companies had human factors groups with average of ten personnel per group (Kraft, JA, 1957). This was around the time when human factors began to be considered important for the safety of people driving cars, owing to the large loss of manpower associated with vehicle accident injuries (Stapp, John et al., 1957). Although at that time the idea revolved around developing machines for use by humans, in due course of time, the idea evolved into the safety of operators of various systems.

As time passed, the concepts of human factors as well as the understanding of the physical and psychological limits and capabilities of human were used to develop systems that would require less physical and mental effort to enable the human to perform tasks better (Karat, John, 1997, Albayrak, Esra et al., 2004). A lot of studies began exploring the effects that workplace elements had on operator task performance (Bosch, T., Mathiassen et al., 2011). Correlations were drawn between the quality of the process/product produced as a result of human-related limitations (Drury, C.G, 2000). Around the 1970s, organizations like NIOSH and OSHA were developed with all this understanding in mind. These organizations had the sole purpose of ensuring worker safety at companies. Following this, human factors began to be applied towards making products and systems usable (Bannon, Liam J, 1995).

Literature has shown that workplace organization has been seen to increase productivity in manufacturing companies (Karwowski, Waldemar et al., 1998). Lean techniques like 5S and Visual Management have been used to manage various aspects of a production process and ensure that there is a place for every item. These techniques have been seen to have a strong correlation to the development of a company's business (Arvanitis, Spyros, 2005). Additionally, there have been studies that have shown that investing in human capital and workplace organization has contributed to the labor productivity in firms across Switzerland and Greece (Arvanitis, Spyros et al. 2009). Some studies have connected workplace organization to human injuries (Shahnavaz, H., 1987).

However, in all of the literature in the field of workplace organization and human factors, there doesn't seem to be a correlation between workplace organization and human factors. All the literature in the field of human factors has talked about safety, human-machine issues, human-centered design of systems and products for use by humans, organizational well-being of workers etc. While there are correlations between changing certain physical characteristics of a workplace and human performance. But nowhere does it mention reorganization of workplaces to enhance human performance, especially, in high-priority work settings. Even though the aviation sector has employed this idea of reorganization of flight instruments to enhance pilot task performance, such a concept has not been applied to a work setting like say a storage room. While techniques like 5S have been employed in storage rooms, there is no correlation between that and human factors. This thesis aims at establishing this link by not changing any variable but the layout of a workspace.

This paper aims to explain the importance of user-centered redesign of storage spaces in high-priority and time-critical scenarios by means of a detailed experimental study that was carried out at a midwestern law enforcement agency. The experimental study involved sworn officers with duties and responsibilities associated with the miscellaneous equipment storage room. The study was comprised of three phases. First, the study was performed on the existing system and the time taken for each task and the time wasted on looking for items were recorded. The data obtained from this experiment, the user surveys, user-centered heuristics and a Simio model developed were used to redesign the storage room for the next phases of the study. The redesign was aimed at creating the most optimal storage room design that would not only enable the easy accomplishment of the tasks at hand, but also fit within the expectations and capabilities of the officers. After the redesign, there was a significant drop in the amount of time wasted looking for equipment in the storage room. The time wasted was translated to a cost associated with wasting time looking for items in the storage rooms. Both the qualitative and quantitative data thus obtained indicated that the redesign would not only make the room easier to navigate, but also would enable the officers to spend more time on actual law enforcement responsibilities by making the process of locating and retrieving items easier. Moreover, the cost associated with the wasted time could be used by to purchase new equipment. The results indicated a very real need for such user-centered interventions in such time-critical scenarios to make tasks easier and quicker to perform and to support the capabilities and limitations of the humans involved in such systems, as has been shown time and again by time-critical industries like the aviation industry for instance. The data thus obtained indicated the need for organizational engineering of storage spaces in such environments.

In the upcoming chapter the journal paper associated with this thesis is discussed with the experiment carried out along with the results obtained and inferences drawn. The last chapter concludes the findings inferred from the thesis.

CHAPTER 2. A USER-CENTERED ENGINEERING APPROACH TO STORAGE AND ACCESS IN HIGH PRIORITY SCENARIOS

Varun Ananthasivan Srikrishnan and Dr. Richard T Stone

Abstract

This paper focuses on the organizational engineering of storage spaces to enable easy location and retrieval of equipment, thus supporting the time-critical nature of operations at a miscellaneous storage room at a midwestern law enforcement agency. The idea is to combine the concept of workplace organization with those of human-centered design to redesign the storage areas to better support the activities of the officers. In order to implement this idea, experiments were carried out on sworn officers with duties using a familiar scenario before and after the redesign of the storage room. After carrying out the first test (before redesign), using user-centered heuristics a Simio model was developed to optimize the redesign of the room to allow for the easiest access and retrieval of items from the room. The redesign was based on this model as well as participant surveys. As a result of the complete redesign, a significant reduction in the wasted time was observed as indicated by a statistical analysis performed. Further qualitative surveys indicated that 79% of the officers found the new system easier and more convenient to use. The use of labels and pictures to identify various shelves in the storage room was found to make the system easier to learn and more intuitive, based on the qualitative surveys. The wasted time calculated was then translated to a cost and the newly designed storage room was found to have reduced the cost by 49%, money that could be spent on actions that precluded the efficient accomplishment of tasks. The quantitative and qualitative results of the study indicate that there is a need for the industry to extend research towards this field that we name "organization engineering".

Introduction and Background

The research interest in of human factors and user-centered design goes back a long way in history. User-centered considerations began around the time of World War II when countries were developing airplanes that could go faster and higher than ever before. Designers began to realize that, in order to be successful in flying these faster aircraft, the pilots' physique needed to be considered during the design process. There was a need to design aircrafts according to the human flying it and to support the capabilities and understanding of the humans flying it. This was one of the first applications of human factors in high priority and time and safety-critical environments. The whole idea of fitting the workplace to the human became an important consideration (Wiener, E. L., & Nagel, D. C. 1988). The early origin and development of the concept of "user-centered design" began in the years following late 1980s during which time a lot of research was being done in this area. Some researchers through years of study and experimentation developed principles of user-centered design that seemed easy to understand and easily applicable to the design of day-to-day products. (Ben Shniederman, 1987; Norman, 1988; Nielsen, 1993, 2001). These principles highlighted the importance of intuitiveness in design.

Following this, many researchers and companies alike began exploring the advantages associated with the incorporating the concepts of human-centered design into the design of products and systems, thus giving their organizations a competitive edge over others in the market (Ahmad and Schroeder, 2003; Onyema, 2014). But there was still a lack of knowledge of human-centered approaches that seemed to have limited the application of human factors to industrial production (Dul and Neumann, 2009). This lack of understanding drove many laboratory experiments and tests in different industrial settings that aimed at providing the advantages of incorporating human factors and ergonomic interventions into the design of everyday objects and process improvement. Many “usability studies” gained popularity during this period. These studies involved changing certain physical characteristics of the work environments, measuring the effect the change had on human performance and studying the overall improvement in the process and product quality (Chaffin, D.B., 2008).

More recently, studies have been done to identify how human-centered approaches can be used in the manufacturing of products and processes to reduce physical workload on employees. However, work related to the application of human-centered approaches to the organizational level is greatly limited. A few studies have incorporated this approach to better relationships between teams, to improve employee morale, to create a work environment that will favor learning and improve employee-management relationships (Leonard et al., 2004, Lank, E., 1997). For example, many companies have incorporated open. One study has touched upon activity-based work environment and its impact on satisfaction. Most studies have looked at human factors as a means of improving the quality products and processes, safety of users/operators performing their task or using the products and to increase their competitive edge over other companies.

Alongside this realization among industries that user-centered approaches were the key towards attracting customers and keeping them loyal and happy, the defense community began to embrace ideas of user-centered design for training personnel. For example, the developing virtual environments that would help train military personnel by providing a visualization of the battlefield (Hix, D et al., 1999) was an important application that the military was interested in. Law enforcement agencies were interested in the development of human-centered spatiotemporal crime analysis tools (Roth, R et al., 2010, 2013) that could greatly help officers spend more of their time on law enforcement duties. User-centered design was also used to enhance situational awareness among officers (Razip, A et al., 2014).

For many decades, the design of exoskeletons (Schnieders, T. et al., 2014) seemed to interest a lot of researchers and defense communities. From design suits for army personnel to their use as prosthetics, extensive research has been performed to develop exoskeletons for various purposes. Most recently, exoskeletons were used in law enforcement for training officers in the use handguns to ensure accurate, precise, reliable and ergonomically safe postures (Schnieders, T. et al., 2019). The need for accuracy and precision in a fast-paces and high-priority/security environments of law enforcement agencies and defense departments seems to make user-centered design very important in such industries.

Theory

Most of literature talks about applying user-centered techniques to the design of products and systems that support human capability. Nowhere in the industry or in literature have there been specific studies that try to link the use of human-centered principles with optimal organization of workplaces. Similar to aviation where different flight controls and avionics need to be organized effectively, there is a real need to organize a workspace in a way that allows the user to spend more time on the task at hand rather than looking for items. This organization can be made based on functional or natural mapping, user evaluations and non-user evaluations. Even though literature has shown that human-centric design can improve the quality of a process, it does not tie the human-centric interventions directly to the performance of the human, there are usually a lot of variables. This paper describes a Human Factors intervention that was carried out in a midwestern law enforcement agency storage room with the aim of enhancing the performance of officers, with only one variable; the changing design of the room alone. In doing so, the hypothesis is that, re-organization of the workspace will enable the officers to locate and retrieve items quickly and efficiently and will enable the officers spend less time on the search and more time on their task at hand.

Methodology

Procedure

Following is a sequential set of actions that were performed throughout the process:

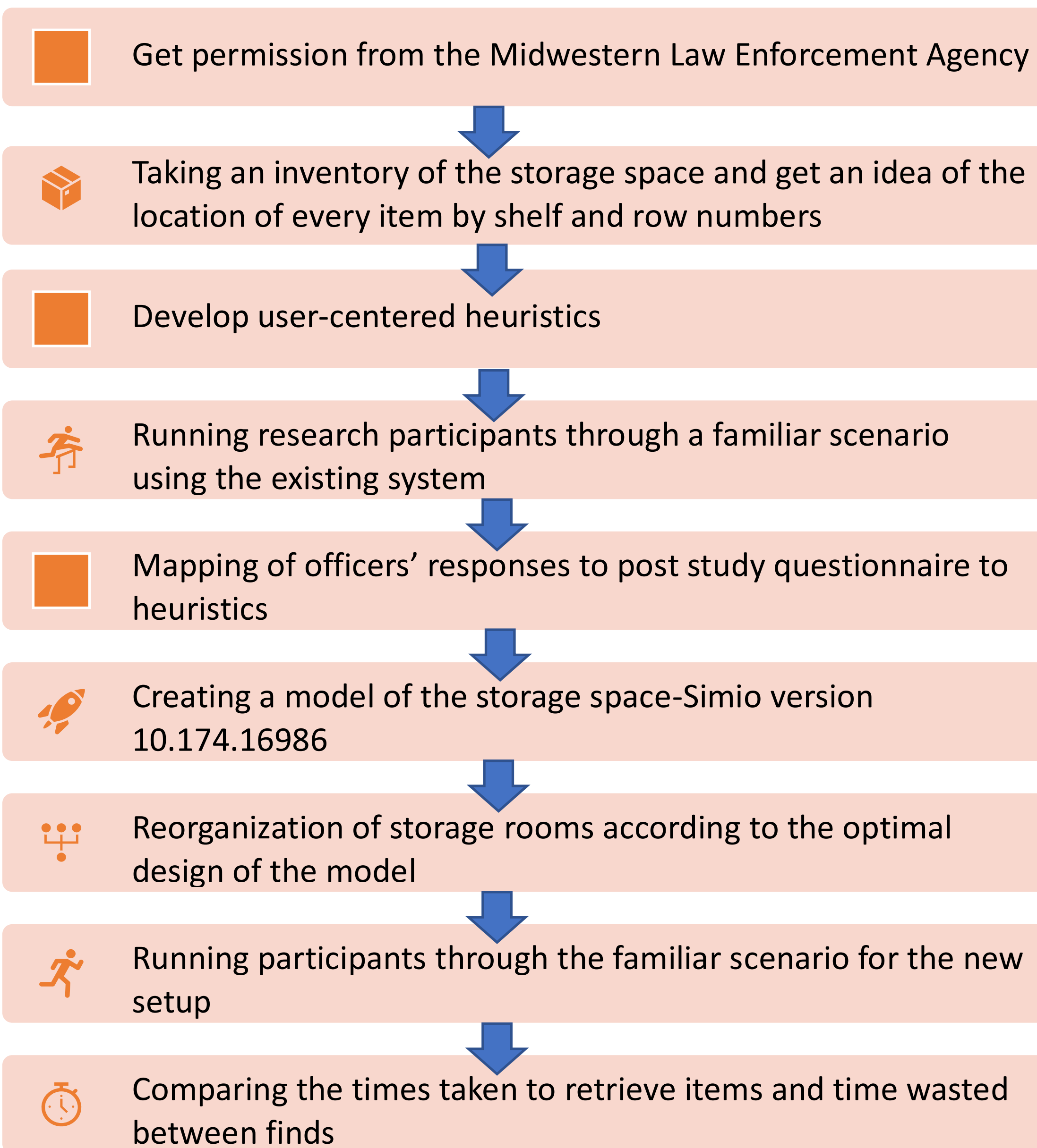


Figure 1: Process Involved in the Study

Participants

Six sworn officers with tasks specific to the miscellaneous equipment storage room participated in this study. They were selected based on the following criteria:

- 18 years or older,
- Employed by the midwestern law enforcement agency
- Able to legally give consent

Independent variable

The independent variable in this experiment was the difference in organization between the existing storage room and that of the new storage room.

Dependent variables

The dependent variable in this experiment was the Time wasted on actions between finds. The reason for considering "Time Wasted" as a dependent variable was that the wasted time was identified to be the part of the time taken to perform the task that when extrapolated to other small tasks that form part of the midwestern law enforcement agency's responsibilities could lead to major loss of time that could instead have been used for more important duties such as serving the community or processing cases. It was believed that if this time could be reduced to the minimum, it would greatly benefit the midwestern law enforcement agency by allowing the officers to spend more time on important tasks at hand. Additionally, the time wasted was assigned a cost based on the time wasted by an officer on finding items and the average hourly salary of deputies at the midwestern law enforcement agency based on the Des Moines Register (2019).

User-Centered Heuristics

Following were the user-centered heuristics (based on the Nielsen–Shneiderman Heuristics) that were considered for the redesign of the storage room:

- Visibility: To ensure that users can see the status of the inventory while retrieving items. The existing system did not afford the officers with the ability to see whether a particular type of item was out or not.
- Consistency: To ensure that certain elements of the existing system were kept as is to avoid any confusions and support easier learnability of the new setup. If changes were such that the new system was too different, that would require the officers to support a longer learning curve and make task performance more difficult.
- Memory: To make location and retrieval quicker symbols and labels were provided. This way, the officers would not need to look for items.
- Flexibility: The new system was designed to enable easy location and retrieval of items for officers at different experience levels.

The study was divided into three phases: the control phase, the improvement phase and experimental phase. Following is a detailed description of the three phases:

Phase 1: Control Phase-Testing Participants on the existing arrangement of the storage rooms-Testing Scenario

The officers were run through a familiar testing scenario. They were asked to retrieve equipment pertaining to the testing scenario; “New Hire scenario”. This scenario was selected as it was a very common scenario faced by the midwestern law enforcement agency, owing to the large number of new hires being added to the team on a regular basis. Besides, it was a relatively easy scenario to test the hypothesis of the study in a clear and unambiguous way.

Testing scenario-New Hire: A scenario where the officers were tasked with giving a newly hired officer essential equipment required for them to begin their duty. This scenario mimics a real-life scenario where a new hire is given equipment like uniforms etc. that is essential for them to be considered officers on duty. They were provided the same list of items that they would use to locate and retrieve equipment in a real scenario. The participants actions were monitored on video for the time associated with the completion of the particular scenario assigned.

Phase 2: Improvement Phase-Updating the Storage Rooms

This phase involved:

- Gathering all the responses provided by the officers in the post study questionnaires
- Using the responses and the user-centered heuristics to develop an optimal room design model using Simio, a simulation software capable of supporting the optimization of resources and layouts of complex systems and scheduling processes: The user-centered heuristics along with the responses provided by officers in the post-study questionnaire were used while developing the model of the storage room using the Simio software; i.e., items were rearranged in the model in such a way that all of the equipment were visible at all times, the room's design was consistent with certain elements of the old design, specifically those called out in the questionnaires (officers called out elements that they liked about the existing system in the questionnaires) , the design did not require officers to memorize the location of items and the new system could easily be navigated through by experienced and inexperienced officers alike. This was followed by creating various designs for the model using Simio (Version 10.174.16986). All storage shelves, cupboards or any stand that hold items to be retrieved at some point were modeled as 'Servers' as are

the obstructions that the existing storage space setup provides to the participants. One 'Source' and one 'Sink' were provided to serve as a point from where participants enter and exit the room, respectively. The model is explained it greater detail with images below. By conducting simulations on various design iterations, an optimal design was selected such that it was in line with the user-centered heuristics and comments and such that it would minimize the time taken to follow the path pertaining to the new hire scenario, created using a list of items used by the midwestern law enforcement agency for the new hire equipment retrieval scenario.

- Reorganizing the storage room based on the most optimal design obtained from Simio: All the items were pulled out from the room and put back into the shelves once the room was reorganized. The items were organized into specific shelves on the basis of most used items, items used together in situations and items whose locations would not be changed based on recommendations by officers in the questionnaires

Simio Model

All the servers represent shelves/obstacles. In the model of the existing system Servers 1-10 represent shelves while the other represent obstacles that hindered the officers' ability to retrieve items. The different paths represent the specific path followed by officers as they go into the room to retrieve equipment pertaining to the scenario at hand: new hire. The simulation was run using an arrival rate of one per min, for a period of 24 hours. The various paths indicated represent the specific path that the officers were constrained by means of a list of equipment to follow to retrieve the equipment pertaining to the scenario at hand; in this case the scenario of giving a new hire all the equipment required for their first day. The arrows represent the direction of movement of officers along the path established by means of the list of items. The small red arrows on the path indicate an officer moving towards a particular shelf. The time taken along each path was recorded by Simio. Adding the times associated with following the paths indicated that the amount of time taken to move from one point to the other in the existing system was twice that of the time taken in the new system. For instance, moving from the source to server 1 required the officers to go through server 13 in case of the existing system while moving the same distance allowed officers to go direct to server 1. In such cases, the time taken was found to be the sum of the times taken along each path. This simulation provided an idea of the potential time wastage associated with the existing system and a need to redesign it to remove all the obstacles that seemed to get in the way of the officers' ability to accomplish the task at hand.

Therefore considering the above attributes as well as the time taken, the new system was designed to keep certain elements of the existing system like the location of uniforms and grooming equipment as per participant surveys collected after the first experiment. In all, the time recorded, participant surveys and feedback, in addition to the human-centered attributes were used to develop the model of the new system.

In this model, the retrieval process follows a fixed path depending on the scenario assigned to the participant. The list of items to pick served as a means of providing for the path. The model is developed according to the task. For example, if a particular task requires a participant to retrieve items from shelf 2, 3, 5, 6 and then to exit the room, the model is developed in such a way that paths are drawn from the source to server 2, server 2 to server 3, server 3 to server 5, server 5 to server 6 and server 6 to the sink. The models were developed for the existing system and the total time taken to retrieve an item and the number of items processed are obtained by running a simulation of the model for 24 hours. Once this was done, an optimal process flow design was developed in such a way that it resulted in the least amount of system time and greatest number of processed items. Some human-centered concerns raised by the officers in the first questionnaire like keeping the grooming section the same as before were also incorporated into the design.

Existing System

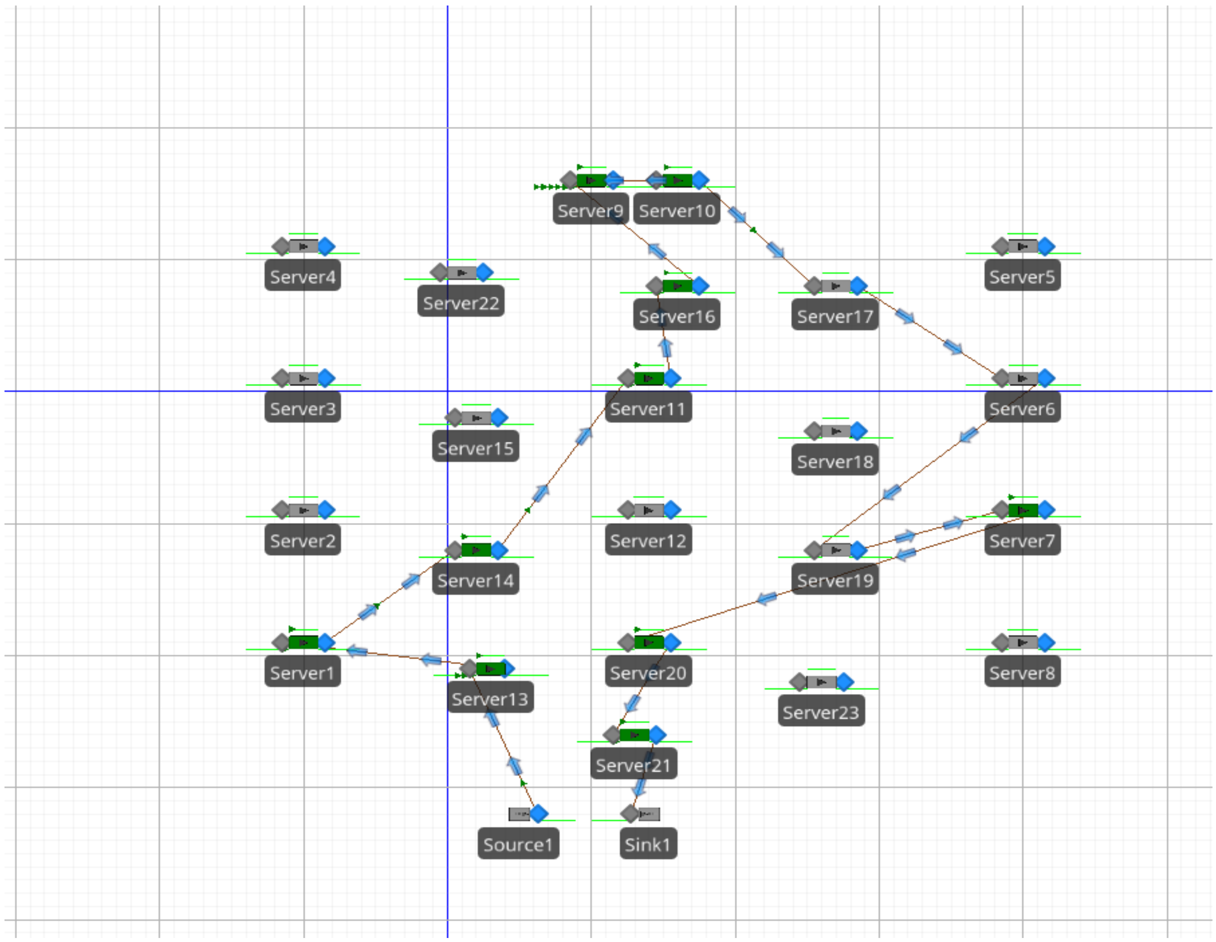


Figure 2: Simio model of the room before user-centered redesign

New System

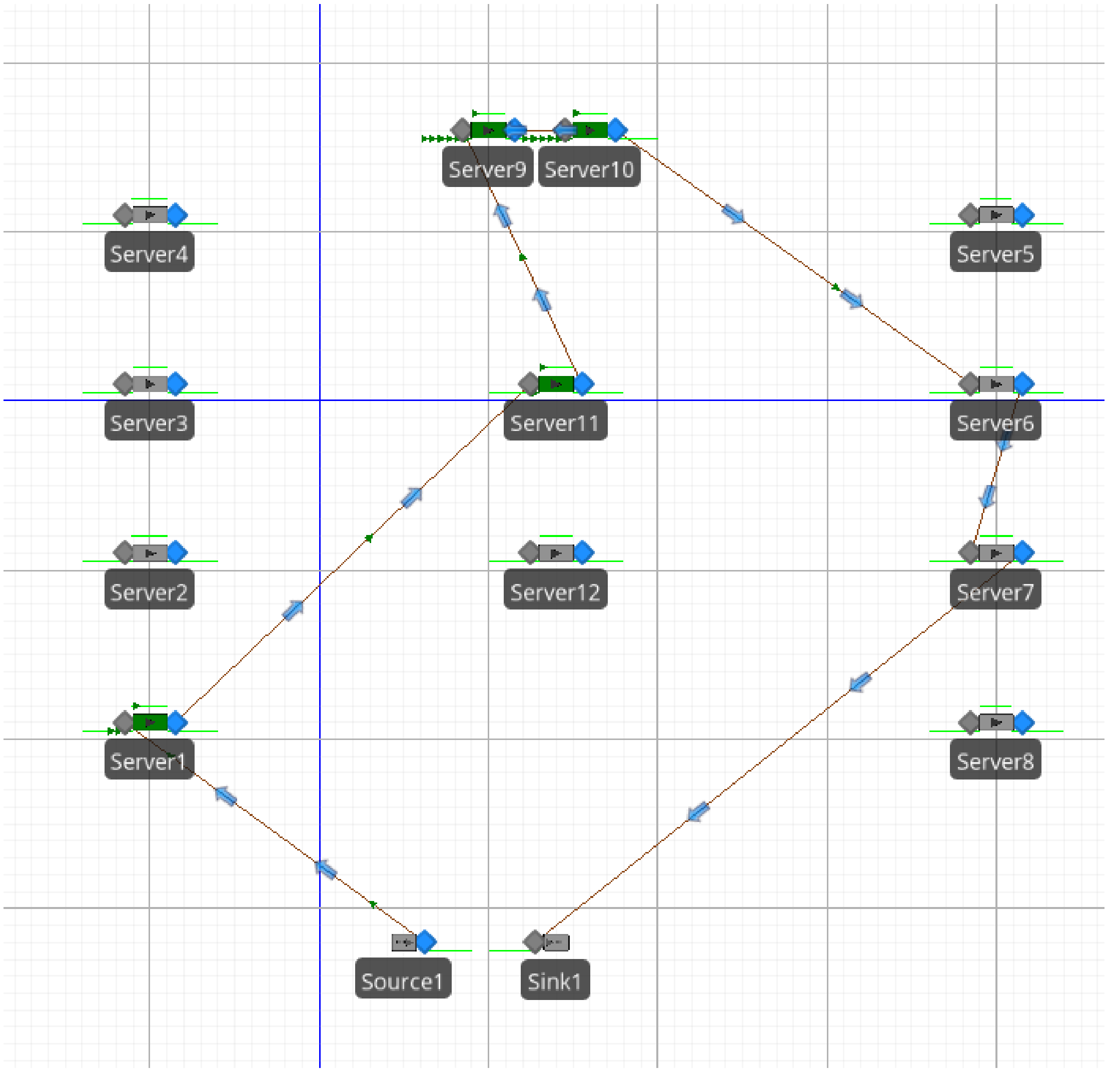


Figure 3: Simio model of the room after user-centered redesign

Phase 3: Experimental Phase-Testing Participants on the updated storage rooms

This phase is more or less the same as Phase 1 with the only exception being that the experiment was carried out on the new and updated. The participants were asked to fill a post-study questionnaire at the end of this phase. The same New hire scenario was employed.

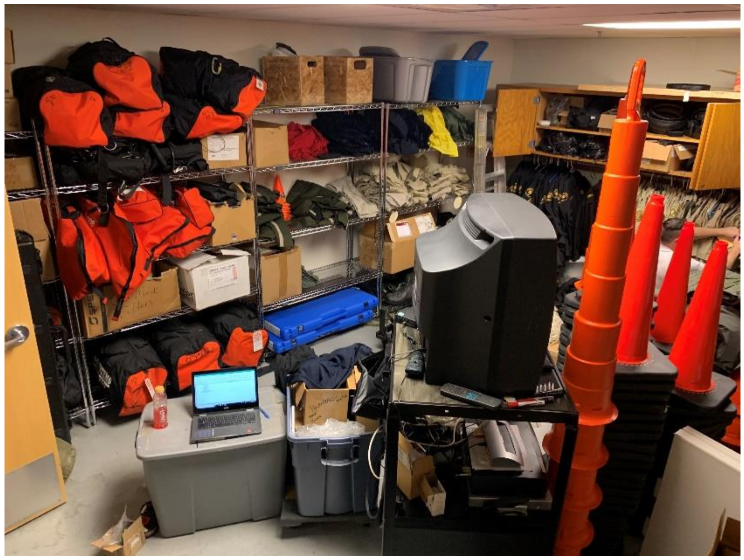


Figure 4: Storage room before user-centered redesign

Figure 5: Storage room after user-centered redesign

Results

Hypothesis

- Null hypothesis: The mean of the time wasted before the redesign/reorganization equals that after the reorganization

- $\mu_{T\_before} = \mu_{T\_after}$

- Alternate hypothesis: Time wasted between finds before the new design is greater than the Time wasted between finds after the new design:
  - $\mu_{T\_before} > \mu_{T\_after}$
- Significance value selected: α=0.05

Quantitative

Table 1: Summary of Quantitative Data

Dependent variable	Before Change	After Change
Average time spent to complete the task	5.87 min	4.90 min
Time wasted on locating equipment	1.81 min	0.93 min
Estimated cost associated with the wasted time per officer	$1610	$828

Cost calculation: Percentage of time wasted x 8 hours a day x 5 days a week x 4 weeks x 12 months x $27.66/hr. (approximate salary of deputy based on the Des Moines Register (2019)).

Table 2: Analysis of Variance

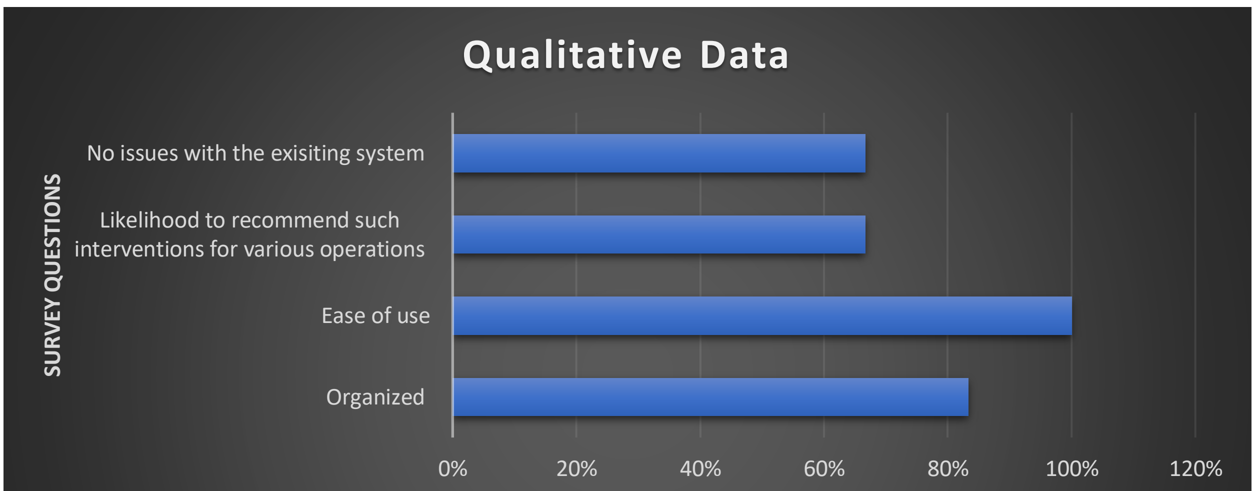
Anova						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Column 1	6	12.05406562	2.009010937	0.031563984		
Column 2	6	10.34944655	1.724907758	0.014331931		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.242143849	1	0.242143849	10.55186929	0.008744678	4.964602744
Within Groups	0.229479576	10	0.022947958			
Total	0.471623425	11				

Table 3: Paired t-test

t-Test: Paired Two Sample for Means		
	Variable 1	*Variable 2*
Mean	2.00901094	1.72490776
Variance	0.03156398	0.01433193
Observations	6	6
Pearson Correlation	0.87565832	
Hypothesized Mean Difference	0	
df	5	
t Stat	7.48371949	
P(T<=t) one-tail	0.00033651	
t Critical one-tail	2.01504837	
P(T<=t) two-tail	0.00067302	
t Critical two-tail	2.57058184	

The data collected indicated a 48% reduction in the time wasted in between finds. Subsequently, there was a 49% drop in the cost associated with this wasted time as a result of the user-centered intervention. An ANOVA performed revealed a p-value of 0.008. This indicates that the null hypothesis can be rejected and a paired t-test performed on these times indicated a p-value of 0.00033 one-tailed (very much less than the significance value of 0.05) indicating that there is a great possibility that there is a statistically significant difference between the time wasted in the older system compared to that of the new system.

Qualitative



	Organized	Ease of use	Likelihood to recommend such interventions for various operations	No issues with the exisiting system
Percentage of Participants	83%	100%	67%	67%

Figure 6: Response collected from post-study questionnaire after the experimental phase

The graph depicts the opinions of the officers with regard to certain heuristics obtained from the post-study questionnaire. It indicates that most of the officers found the system organized, easy to use and issue-free. They even expressed that such interventions would greatly help with other operations at the midwestern law enforcement agency.

Discussion

The results suggest that the re-organization of the storage room reduced the amount of time spent on looking for items, identifying them and navigating around items on the floor was reduced by 17%. The reason for the almost similar amount of time to complete the task can be owed to the lack of familiarity of the new system. The significantly lower amount of wasted time as evidenced by the ANOVA and paired t-test performed on the time wasted before and after the changes that indicated p-values of 0.008 and 0.00033 respectively suggests that the two times are significantly different with the time wasted before the change being significantly larger than that of the time wasted after the redesign.

Additionally, a 49% reduction in the cost associated with the wasted time was observed. The new design reduced the amount of time wasted in between finds significantly. This suggests that the midwestern law enforcement agency could spend the money saved by the new system for purposes that would help it serve the community better. Both the quantitative and qualitative data obtained suggested that the design of the system greatly supported the mental model of the participants. This was an important consideration during the redesign of the room that enabled easier learnability to support new and experienced officers alike and reduced confusion associated with the new system to an extent (Rouse, W.B et al., 1992).

Almost all of the officers who participated in the experiment reported to have found the system to be organized and intuitive to use. Many of them recommended the expansion of this area we call “organizational engineering” to other operations within the midwestern law enforcement agency as well as those in other high-priority work settings. Above all, the data obtained indicated a strong relation between human-centered design approaches and workplace design.

Unlike whatever was done earlier in literature (Karwowski, W et al. 1998), this study provided a direct link between human-centered principles and organization of workplaces. No variables but the design of the room was changed during the study.

Conclusion

Since the participant surveys indicated that the new system was easy to navigate and that it could be used even by officers who are new, this study serves as a baseline study for more research in this new area of “organization engineering”.

Future work could involve performing such interventions in different storage and inventory spaces and can serve as a means of developing a model for developing a cost-benefit model that could justify such interventions.

References

1. Ahmad, S., Schroeder, R., 2003. The impact of human resource management practices on operational performance: recognizing country and industry differences. J. Oper. Manag. 21 (1), 19–43.

2. Albayrak, E., & Erensal, Y. C. (2004). Using analytic hierarchy process (AHP) to improve human performance: An application of multiple criteria decision-making problem. *Journal of Intelligent Manufacturing*, *15*(4), 491-503.

3. Arvanitis, S., & Loukis, E. N. (2009). Information and communication technologies, human capital, workplace organization and labour productivity: A comparative study based on firm-level data for Greece and Switzerland. *Information Economics and Policy*, *21*(1), 43-61.

4. Arvanitis, S. (2005). Computerization, workplace organization, skilled labour and firm productivity: Evidence for the Swiss business sector. *Economics of innovation and new technology*, *14*(4), 225-249.

5. Bannon, L. J. (1995). From human factors to human actors: The role of psychology and human-computer interaction studies in system design. In *Readings in Human–Computer Interaction* (pp. 205-214). Morgan Kaufmann.

6. Birmingham, H. P., & Taylor, F. V. (1954). *A human engineering approach to the design of man-operated continuous control systems* (No. NRL-4333). NAVAL RESEARCH LAB WASHINGTON DC.

7. Bosch, T., Mathiassen, S.E., Visser, B., de Looze, M.P., van Dieën, J.H., 2011. The effect of work pace on workload, motor variability and fatigue during simulated light assembly work. Ergonomics 54 (2), 154–168. 4 (1), 41–74.

8. Clegg, C., Axtell, C., Damodaran, L., Farbey, B., Hull, R., Lloyd-Jones, R., ... & Tomlinson, C. (1997). Information technology: a study of performance and the role of human and organizational factors. *Ergonomics*, *40*(9), 851-871.

9. Chapanis, A., Garner, W. R., & Morgan, C. T. (1949). Applied experimental psychology: Human factors in engineering design.

10. Drury, C.G., 1997. Ergonomics and the quality movement. Ergonomics 40 (3), 249–264.

11. Drury, C.G., 2000. Global quality: linking ergonomics and production. Int. J. Prod. Res. 38 (17), 4007–4018.

12. Drury, C.G., Maheswar, G., Das, A., Helander, M.G., 2001. Improving visual inspection using binocular rivalry. Int. J. Prod. Res. 39 (10), 2143–2153.

13. Drury, C. G. (2000). Human factors and quality: Integration and new directions. *Human Factors and Ergonomics in Manufacturing & Service Industries*, *10*(1), 45-59.

14. Dul, J., 2003. Ergonomics in management. In: Proceedings of the XVth Triennial Congress of the International Ergonomics Association and the 7th Joint Conference of the Ergonomics Society of Korea. Seoul, Korea, pp. 5–6.

15. Dul, J., Neumann, W.P., 2009. Ergonomics contributions to company strategies. Appl. Ergon. 40 (4), 745–752.

16. Dul, J., Bruder, R., Buckle, P., Carayon, P., Falzon, P., Marras, W. S., & van der Doelen, B. (2012). A strategy for human factors/ergonomics: developing the discipline and profession. *Ergonomics*, *55*(4), 377-395.

17. Falck, A.-C., Ortengren, R., Rosenqvist, M., Soderberg, R., 2017. Proactive assessment of basic complexity in manual assembly: development of a tool to predict and control operator-induced quality errors. Int. J. Prod. Res. 55 (15), 4248–4260

18. Fitts, P. M., Viteles, M. S., Barr, N. L., Brimhall, D. R., Finch, G., Gardner, E., ... & Stevens, S. S. (1951). *Human engineering for an effective air-navigation and traffic-control system, and appendixes 1 thru 3*. OHIO STATE UNIV RESEARCH FOUNDATION COLUMBUS.

19. Grosse, E.H., Glock, C.H., Neumann, W.P., 2017. Human factors in order picking: a content analysis of the literature. Int. J. Prod. Res. 55 (5), 1260–1276.

20. Haber, S.B., O'Brien, J.N., Metlay, D.S., & Crouch, D.A. (1991). Influence of organizational factors on performance reliability (NUREG/CR--5538-Vol1). United States.

21. Hix, D., Swan, J. E., Gabbard, J. L., McGee, M., Durbin, J., & King, T. (1999, March). User-centered design and evaluation of a real-time battlefield visualization virtual environment. In *Proceedings IEEE Virtual Reality (Cat. No. 99CB36316)* (pp. 96-103). IEEE.

22. Karat, J. (1997). Evolving the scope of user-centered design. *Communications of the ACM*, *40*(7), 33-39.

23. Karwowski, W., & Salvendy, G. (Eds.). (1998). *Ergonomics in manufacturing: raising productivity through workplace improvement*. Society of Manufacturing Engineers.

24. Kraft, J. A. (1958). A Follow-up Survey of Human Factors Research in Aircraft, Missiles, and Supporting Industries. Human Factors, 1(1), 23–25. https://doi.org/10.1177/001872085800100105.

25. Lank, E. (1997). Leveraging invisible assets: the human factor. *Long range planning*, *30*(3), 406-412.

26. Leonard, M., Graham, S., & Bonacum, D. (2004). The human factor: the critical importance of effective teamwork and communication in providing safe care. *BMJ Quality & Safety*, *13*(suppl 1), i85-i90.

27. Onyema, E.O., 2014. Assessing the relationship between human resource management and employee job satisfaction: a case study of a food and beverage company. J. Bus. Adm. Res. 3 (1), 71–81.

28. Parasuraman, R. (2000). Designing automation for human use: empirical studies and quantitative models. *Ergonomics*, *43*(7), 931-951.

29. Razip, A. M., Malik, A., Afzal, S., Potrawski, M., Maciejewski, R., Jang, Y., ... & Ebert, D. S. (2014, March). A mobile visual analytics approach for law enforcement situation awareness. In *2014 IEEE Pacific Visualization Symposium* (pp. 169-176). IEEE

30. Register, Des Moines. “Database: Des Moines Area City and County Employee Salaries.” *DesMoinesRegister.com*, 2019, db.desmoinesregister.com/2013-local-salaries/page=3&ordercol=col9&orderdir=desc&searchterms%5Bcol2%7Ccol3%7Ccol4%5D=&searchterms%5Bcol1%5D=&searchterms%5Bcol5%5D=&searchterms%5Bcol6%5D=.

31. Roth, R. E., Ross, K. S., Finch, B. G., Luo, W., & MacEachren, A. M. (2010, September). A user-centered approach for designing and developing spatiotemporal crime analysis tools. In Proceedings of GIScience (Vol. 15). sn.

32. Roth, R. E., Ross, K. S., Finch, B. G., Luo, W., & MacEachren, A. M. (2013). Spatiotemporal crime analysis in US law enforcement agencies: Current practices and unmet needs. *Government Information Quarterly*, *30*(3), 226-240.

33. Rouse, W. B., Cannon-Bowers, J. A., & Salas, E. (1992). The role of mental models in team performance in complex systems. *IEEE transactions on systems, man, and cybernetics, 22*(6), 1296-1308.

34. SA, Federal Aviation Administration, US Department of Transportation. (2013). *Advisory Circular.*

35. Schniders, T., Stone, R., Oviatt, T., Danford-Klein, E., "ARCtiC LawE – An Upper Body Exoskeleton for Firearm Training" Augmented Human, (accepted), 2016.

36. Schnieders, T. M. (2019). *A top-down human-centered approach to exoskeleton design* (Doctoral dissertation, ProQuest Dissertations Publishing).

37. Stapp, J. P., & Lewis, S. T. (1957). Human Factors of Crash Protection in Automobiles. *SAE Transactions*, 488-492.

38. Theberge, N., Neumann, W.P., 2013. The relative role of safety and productivity in Canadian ergonomists' professional practices. Relations Industrielles/Industrial Relations 68, 387–408.

39. Wiener, E. L., & Nagel, D. C. (Eds.). (1988). *Human factors in aviation*. Gulf Professional Publishing.

40. Yerkes, R. M. (1941). Man-power and military effectiveness: The case for human engineering. *Journal of Consulting Psychology*, *5*(5), 205.

CHAPTER 3. GENERAL CONCLUSION

The quantitative data obtained indicated that the newly organized storage room reduced the amount of time wasted in between finds significantly, as evidenced by the ANOVA and paired t-test of the wasted time before and after the change that revealed p-values of 0.008 and 0.00033 respectively for a significance value of 0.05. The cost associated with this wasted time was seen to have reduced by 49%. This suggests that adopting the new design would allow the officer to use the money that was once spent on the wasted time in the old system to purchase equipment that could aid the midwestern law enforcement agency in accomplishing its tasks and serving the community.

The qualitative data obtained indicated that the new system was more intuitive and easier to navigate through. The surveys indicated that most of the officers found the system more organized, easier to learn and consistent with certain elements of the older system that were preferred by the officers. Making the system consistent was seen as a means of supporting the mental model that the officers already had about the room and the location of various equipment. As a result, the officers did not spend a lot of time learning the new system. Thus, the organized rearrangement of the room, the labels and symbols provided on shelves and cupboards and the consistent design complete with careful mapping of the shelves to afford retrieval of the right items were seen to made the location and retrieval process easy and more intuitive.

The cost associated with the wasted tine was calculated over the whole work day to indicate that operations such as the location and retrieval of items could lead to a waste of time if it is not made as efficient as possible. This would potentially rob the midwestern law enforcement agency of precious time that could be used on more important tasks such as solving crimes and serving the community. As a result, the data this obtained indicates that the area of "organizational engineering" needs to be expanded and applied to other such operations in time-critical settings like law enforcement to allow the agency to spend more time on matters requiring greater attention.

The results of the experiments indicate that using user inputs and user-centered heuristics to redesign a workplace setting is very effective in improving the productivity of the operation. Designing the system around the user takes into account the capabilities and limitations of the humans using the system and as such helps the human to perform the tasks associated to the best of their capabilities and in turn improves productivity. The future work should focus on expanding this field to other time critical scenarios with law enforcement and beyond. Additionally, human-centered models can be created that can justify costs and benefits associated with the implementation of such interventions that can expand the adaptation of human-centered approaches to a variety of industry types.

APPENDIX A. PRE-STUDY QUESTIONNAIRE

Pre-Study Questionnaire

1. How often do you use this room?

2. What circumstances, based on your experience have required you to access the equipment in this room?

3. Can you list some items that you take out most frequently?

4. Can you list some items that you take out least frequently?

5. Have you ever experienced a shortage of equipment when you went to look for something? If so, what was your next course of action?

6. Do you see any issues with the existing system? If so, can you list some changes that you would like to see implemented?

APPENDIX B. POST-STUDY QUESTIONNAIRE

Post-Study Questionnaire

1. What are your thoughts on the new system?

2. On a scale of 1-10 (1 being very easy and 10 being very difficult), how easy or difficult did you find the new system?

3. Based on the new system, how likely on a scale from 1-5 (1 being least likely and 5 being most likely) are you to recommend such interventions for various operations at SCSO and other industries?

4. Are there any issues with the new system? If so, please list some things that could help us improve the system.

APPENDIX C. IRB MEMO

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Institutional Review Board
Office for Responsible Research
Vice President for Research
2420 Lincoln Way, Suite 202
Ames, Iowa 50014
515 294-4566

Date: 11/13/2019

To: Varun-Ananthasivan-S Varun-Ananthasivan-Srikri Richard T Stone

From: Office for Responsible Research

Title: **A USER-CENTERED ENGINEERING APPROACH TO STORAGE AND ACCESS IN HIGH PRIORITY SCENARIOS**

IRB ID: **19-504**

Submission Type: Initial Submission **Exemption Date:** 11/13/2019

The project referenced above has been declared exempt from most requirements of the human subject protections regulations as described in 45 CFR 46.104 or 21 CFR 56.104 because it meets the following federal requirements for exemption:

2018 - 2 (ii): Research that only includes interactions involving educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior (including visual or auditory recording) when any disclosure of the human subjects' responses outside the research would not reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, educational advancement, or reputation.
2018 - 3 (i.B): Research involving benign behavioral interventions in conjunction with the collection of information from an adult subject through verbal or written responses or audiovisual recording when the subject prospectively agrees to the intervention and information collection and any disclosure of the human subjects' responses outside the research would not reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, educational advancement, or reputation. - 3 (ii) If research involves deception, it is prospectively authorized by the subject.

The determination of exemption means that:

- **You do not need to submit an application for continuing review. Instead, you will receive a request for a brief status update every three years. The status update is intended to verify that the study is still ongoing.**
- **You must carry out the research as described in the IRB application.** Review by IRB staff is required prior to implementing modifications that may change the exempt status of the research. In general, review is required for any *modifications to the research procedures* (e.g., method of data collection, nature or scope of information to be collected, nature or duration of behavioral interventions, use of deception, etc.), any change in *privacy or confidentiality protections*, modifications that result in the *inclusion of participants from vulnerable populations*, removing plans for informing participants about the study, any *change that may increase the risk or discomfort to participants, and/or* any change such

that the revised procedures do not fall into one or more of the regulatory exemption categories. The purpose of review is to determine if the project still meets the federal criteria for exemption.

- All ***changes to key personnel*** must receive prior approval.
- **Promptly inform the IRB of any addition of or change in federal funding for this study.** Approval of the protocol referenced above applies only to funding sources that are specifically identified in the corresponding IRB application.

Detailed information about requirements for submitting modifications for exempt research can be found on our website. For modifications that require prior approval, an amendment to the most recent IRB application must be submitted in IRBManager. A determination of exemption or approval from the IRB must be granted before implementing the proposed changes.

Non-exempt research is subject to many regulatory requirements that must be addressed prior to implementation of the study. Conducting non-exempt research without IRB review and approval may constitute non-compliance with federal regulations and/or academic misconduct according to ISU policy.

Additionally:

- All research involving human participants must be submitted for IRB review. **Only the IRB or its designees may make the determination of exemption**, even if you conduct a study in the future that is exactly like this study.
- **Please inform the IRB if the Principal Investigator and/or Supervising Investigator end their role or involvement with the project** with sufficient time to allow an alternate PI/Supervising Investigator to assume oversight responsibility. Projects must have an **eligible PI** to remain open.
- **Immediately inform the IRB of** (1) **all serious and/or unexpected adverse experiences** involving risks to subjects or others; and (2) **any other unanticipated problems involving risks** to subjects or others.
- **Approval from other entities may also be needed.** For example, access to data from private records (e.g., student, medical, or employment records, etc.) that are protected by FERPA, HIPAA or other confidentiality policies requires permission from the holders of those records. Similarly, for research conducted in institutions other than ISU (e.g., schools, other colleges or universities, medical facilities, companies, etc.), investigators must obtain permission from the institution(s) as required by their policies. **An IRB determination of exemption in no way implies or guarantees that permission from these other entities will be granted.**
- Your research study may be subject to **post-approval monitoring by Iowa State University's Office for Responsible Research**. In some cases, it may also be subject to formal audit or inspection by federal agencies and study sponsors.
- Upon completion of the project, transfer of IRB oversight to another IRB, or departure of the PI and/or Supervising Investigator, please initiate a Project Closure in IRBManager to officially close the project. For information on instances when a study may be closed, please refer to the IRB Study Closure Policy.

Please don't hesitate to contact us if you have questions or concerns at 515-294-4566 or IRB@iastate.edu.